Chapter 11: CWIS Impingement & Entrainment (I&E) Impacts & Potential Benefits

INTRODUCTION

This chapter presents data reported by existing facilities that indicate the magnitude of impingement and entrainment when once-through cooling is used. The data show that the numbers of organisms impinged and entrained under once-through cooling are nontrivial. EPA was unable to conduct a detailed, quantitative analysis of the potential economic benefits of using closed-cycle instead of once-through cooling because much of the information needed to quantify and value potential reductions in I&E was unavailable. At present, EPA has only general information about the location of potential new facilities, and in most cases details of facility and environmental characteristics are unknown. To overcome these limitations, this chapter presents examples of I&E rates and potential regulatory benefits based on a subset of existing facilities for which information was readily available. The focus is on fish species because very large numbers of fish are impinged and entrained compared to other aquatic organisms such as phytoplankton and benthic invertebrates.

The data presented are numbers of organisms that are directly impinged and entrained. While EPA recognizes that impingement and entrainment losses may result in indirect effects on populations and other higher levels of biological organization, this chapter focuses on impingement and entrainment because these are the direct biological impacts that result from withdrawal of cooling water by CWIS. The final section of the chapter presents information on the potential benefits of installing technologies to reduce impingement and entrainment. These benefits may be illustrative of the benefits that would occur at the estimated nine new facilities that would install the Track I flow reduction technology (closed-cycle cooling) as a result of this rule.

CHAPTER CONTENTS:

The chapter

- summarizes factors related to intake location, design, and capacity that influence the magnitude of I&E;
- discusses CWIS I&E impacts for different water body types (rivers, lakes and reservoirs, the Great Lakes, oceans, and estuaries); and
- provides results from studies of existing facilities indicating the potential economic benefits of lower intake flows and other measures taken to reduce impingement and entrainment.

11.1 CWIS Characteristics that Influence the Magnitude of I&E

11.1.1 Intake Location

Two major components of a CWIS's location that influence the relative magnitude of I&E are (1) the type of water body from which a CWIS is withdrawing water, and (2) the placement of the CWIS relative to sensitive biological areas within the water body. EPA's regulatory framework is designed to take both of these factors into account.

Critical physical and chemical factors related to siting of an intake include the direction and rate of water body flow, tidal influences, currents, salinity, dissolved oxygen levels, thermal stratification, and the presence of pollutants. The withdrawal of water by an intake can change ambient flows, velocities, and currents within the source water body, which may cause organisms to concentrate in the vicinity of an intake or reduce their ability to escape a current.

In large rivers, withdrawal of water may have little effect on flows because of the strong, unidirectional nature of ambient currents. In contrast, lakes and reservoirs have small ambient flows and currents, and therefore a large intake flow can significantly alter current patterns. In addition, tidal currents in estuaries or tidally-influenced sections of rivers can carry organisms past intakes multiple times, thereby increasing their probability of entrainment.

Also, species with planktonic (free-floating) early life stages have higher rates of entrainment because they are unable to actively avoid being drawn into the intake flow.

Considerations in siting an intake to reduce the potential for I&E include intake depth and distance from the shoreline in relation to the physical, chemical, and biological characteristics of the source water body. In general, intakes located in nearshore areas (riparian or littoral zones) will have greater ecological impact than intakes located offshore, because nearshore areas are more biologically productive and have higher concentrations of organisms.

Siting of intake withdrawal in relation to the discharge site is also important because if intake withdrawal and discharge are in close proximity, entrained organisms released in the discharge can become re-entrained.

The magnitude of I&E in relation to intake location also depends on biological factors such as species' distributions and the presence of critical habitats within an intake's zone of influence.

11.1.2 Intake Design

Intake design refers to the design and configuration of various components of the intake structure, including screening systems (trash racks, pumps, pressure washes), passive intake systems, and fish diversion and avoidance technologies (U.S. EPA, 1976).

Design intake velocity has a significant influence on the potential for impingement (Boreman, 1977). The biological significance of design intake velocity depends on species-specific characteristics, such as fish swimming ability and endurance. These characteristics are a function of the size of the organism and the temperature and oxygen levels of water in the area of the intake (U.S. EPA, 1976). The maximum velocity protecting most small fish is 0.5 ft/s, but lower velocities will still impinge some fish and entrain eggs and larvae and other small organisms (Boreman, 1977). After entering the CWIS, water must pass through a screening device before entering the power plant. The screen is designed to prevent debris from entering and clogging the condenser tubes. Screen mesh size and velocity characteristics are two important design features of the screening system that influence the potential for impingement and entrainment of aquatic organisms that are withdrawn with the cooling water (U.S. EPA, 1976).

Conventional traveling screens have been modified to improve fish survival of screen impingement and spray wash removal (Taft, 1999). However, a review of steam electric utilities indicated that these alternative screen technologies are usually not much more effective at reducing impingement than the conventional vertical traveling screens used by most steam electric facilities (SAIC, 1994). An exception may be traveling screens modified with fish collection systems (e.g., Ristroph screens). Studies of improved fish collection baskets at Salem Generating Station showed increased survival of impinged fish (Ronafalvy et al., 1999).

Passive intake systems (physical exclusion devices) screen out debris and aquatic organisms with minimal mechanical activity and low withdrawal velocities (Taft, 1999). The most effective passive intake systems are wedge-wire screens and radial wells (SAIC, 1994). A new technology, the Gunderboom, which consists of polyester fiber strands pressed into a water-permeable fabric mat, has shown promise in reducing ichthyoplankton entrainment at the Lovett Generating Station on the Hudson River (Taft, 1999).

Fish diversion/avoidance systems (behavioral barriers) take advantage of natural behavioral characteristics of fish to guide them away from an intake structure or into a bypass system (SAIC, 1994; Taft, 1999). The most effective of these technologies are velocity caps, which divert fish away from intakes, and underwater strobe lights, which repel some species (Taft, 1999). Velocity caps are used mostly at offshore facilities and have proven effective in reducing impingement (e.g., California's San Onofre Nuclear Generating Station, SONGS).

Another important design consideration is the orientation of the intake in relation to the source water body (U.S. EPA, 1976). Conventional intake designs include shoreline, offshore, and approach channel intakes. In addition, intake operation can be modified to reduce the quantity of source water withdrawn or the timing, duration, and frequency of water withdrawal. This is an important way to reduce entrainment. For example, larval entrainment at the San Onofre facility was reduced by 50% by rescheduling the timing of high volume water withdrawals (SAIC, 1996).

11.1.3 Intake Capacity

Intake capacity is a measure of the volume or quantity of water withdrawn or flowing through a cooling water intake structure over a specified period of time. Intake capacity can be expressed as millions or billions of gallons per day (MGD or BGD), or as cubic feet per second (cfs). Capacity can be measured for the facility as a whole, for all of the intakes used by a single unit, or for the intake structure alone. In defining an intake's capacity it is important to distinguish between the *design* intake flow (the maximum possible) and the *actual* operational intake flow. For this regulation, EPA is regulating the total design intake flow of the facility.

The quantity of cooling water needed and the type of cooling system are the most important factors determining the quantity of intake flow (U.S. EPA, 1976). Once-through cooling systems withdraw water from a natural water body, circulate the water through condensers, and then discharge it back to the source water body. Closed-cycle cooling systems withdraw water from a natural water body, circulate the water through the condensers, and then send it to a cooling tower or cooling pond before recirculating it back through the condensers. Because cooling water is recirculated, closed-cycle systems generally use only 3.4% to 28.8% of the water used by once-through systems[1] (Kaplan, 2000). It is generally assumed that this will result in a comparable reduction in I&E (Goodyear, 1977). Systems with helper towers reduce water usage much less. Plants with helper towers can operate in once-through or closed-cycle modes.

Circulating water intakes are used by once-through cooling systems to continuously withdraw water from the cooling water source. The typical circulating water intake is designed to use 0.03-0.1 m^3/s (1.06-3.53 cfs, or 500-1500 gallons per minute, gpm) per megawatt (MW) of electricity generated (U.S. EPA, 1976). Closed-cycle systems use makeup water intakes to provide water lost by evaporation, blowdown, and drift. Although makeup quantities are only a fraction of the intake flows of once-through systems, quantities of water withdrawn can still be significant, especially by large facilities (U.S. EPA, 1976).

Assuming that organisms are uniformly distributed in the vicinity of an intake, the proportion of the source water flow

[1] The difference in water usage in cooling towers results from differences in source water (salinity) and the temperature rise of the system.

supplied to a CWIS is often used to derive a conservative estimate of the potential for adverse impact (e.g., Goodyear, 1977). For example, withdrawal of 5% of the source water flow may be expected to result in a loss of 5% of planktonic organisms. Although the assumption of uniform distribution may not always be met, when data on actual distributions are unavailable, simple mathematical models based on this assumption provide a conservative and easily applied method for predicting potential losses (Goodyear, 1977).

In addition to the relative quantity of intake flow, the potential for aquatic organisms to be impinged or entrained also depends on physical, chemical, and biological characteristics of the surrounding ecosystem and species characteristics that influence the intensity, time, and spatial extent of contact of aquatic organisms with a facility's CWIS. Table 11-1 lists CWIS characteristics and ecosystem characteristics that influence when, how, and why aquatic organisms may become exposed to, and experience adverse effects of, CWIS.

Table 11-1: Partial List of CWIS, Ecosystem, and Species Characteristics Influencing Potential for I&E

CWIS Characteristics[a]	Ecosystem and Species Characteristics

Location
‣ Depth of intake
‣ Distance from shoreline
‣ Proximity of intake withdrawal and discharge
‣ Proximity to other industrial discharges or water withdrawals
‣ Proximity to an area of biological concern
 	
Design
‣ Type of intake structure (size, shape, configuration, orientation)
‣ Design intake velocity
‣ Presence/absence of intake control and fish protection technologies
  ‣ Intake Screen Systems
  ‣ Passive Intake Systems
  ‣ Fish Diversion/Avoidance Systems
‣ Water temperature in cooling system
‣ Temperature change during entrainment
‣ Duration of entrainment
‣ Use of intake biocides and ice removal technologies
‣ Scheduling of timing, duration, frequency, and quantity of water withdrawal.
 	
Capacity
‣ Type of withdrawal — once-through vs. recycled (cooling water volume and volume per unit time)
‣ Ratio of cooling water intake flow to source water flow
	Ecosystem Characteristics (abiotic environment)
	‣ Source water body type
	‣ Water temperatures
	‣ Ambient light conditions
	‣ Salinity levels
	‣ Dissolved oxygen levels
	‣ Tides/currents
	‣ Direction and rate of ambient flows
	
	Species Characteristics (physiology, behavior, life history)
	‣ Density in zone of influence of CWIS
	‣ Spatial and temporal distributions (e.g., daily, seasonal, annual migrations)
	‣ Habitat preferences (e.g., depth, substrate)
	‣ Ability to detect and avoid intake currents
	‣ Swimming speeds
	‣ Mobility
	‣ Body size
	‣ Age/developmental stage
	‣ Physiological tolerances (e.g., temperature, salinity, dissolved oxygen)
	‣ Feeding habits
	‣ Reproductive strategy
	‣ Mode of egg and larval dispersal
	‣ Generation time

[a] All of these CWIS characteristics can potentially be controlled to minimize adverse environmental impacts (I&E) of new facilities.

If the quantity of water withdrawn is large relative to the flow of the source water body, a larger number of organisms will potentially be affected by a facility's CWIS.

11.2 Methods for Estimating Potential I&E Losses

11.2.1 Development of a Database of I&E Rates

To estimate the relative magnitude of I&E for different species and water body types, EPA compiled I&E data from 107 documents representing a variety of sources, including previous section 316(b) studies, critical reviews of section 316(b) studies, biomonitoring and aquatic ecology studies, and technology implementation studies. In total, data were compiled for 98 steam electric facilities (36 riverine facilities, 9 lake/reservoir facilities, 19 facilities on the Great Lakes, 22 estuarine facilities, and 12 ocean facilities). Design intake flows at these facilities ranged from a low of 19.7 to a high of 3,315.6

MGD.

EPA notes that most of these studies were completed by the facilities in the mid-1970s using methods that are now outmoded. A number of the methods used at that time probably resulted in an underestimate of losses. For example, many studies did not adjust I&E sampling data for factors such as collection efficiency. Because of such methodological weaknesses, EPA used these only to gauge the relative magnitude of impingement and entrainment losses. Any further analysis of the data should be accompanied by a detailed evaluation of study methods and supplemented with additional data as needed.

In order to understand the potential magnitude of I&E, EPA aggregated the data in the studies in a series of steps to derive average annual impingement and entrainment rates, on a per facility basis, for different species and water body types.

First, the data for each species were summed across all units of a facility and averaged across years (e.g., 1972 to 1976). Losses were then averaged by species for all facilities in the database on a given water body type to derive species-specific and water body-specific mean annual I&E rates. Finally, mean annual I&E rates were ranked, and rates for the top 15 species were used for the data presented below.

11.2.2 Data Uncertainties and Potential Biases

A number of uncertainties and potential biases are associated with the annual I&E estimates that EPA developed. Most important, natural environmental variability makes it difficult to detect ecological impacts and identify cause-effect relationships even in cases where study methods are as accurate and reliable as possible. For example, I&E rates for any given population will vary with annual changes in environmental conditions. As a result, it can be difficult to determine the relative role of I&E mortality in population fluctuations.

In addition to the influence of natural variability, data uncertainties result from measurement errors, some of which are unavoidable. Much of the data presented here does not account for the inefficiency of sampling gear, variations in collection and analytical methods, or changes in the number of units in operation or technologies in use.

Potential biases were also difficult to control. For example, many studies presented data for only a subset of "representative" species, which may lead to an underestimation of total I&E. On the other hand, the entrainment estimates obtained from EPA's database do not take into account the high natural mortality of egg and larval stages and therefore are likely to be biased upwards. However, this bias was unavoidable because most of the source documents from which the database was derived did not estimate losses of early life stages as an equivalent number of adults, or provide information for making such calculations.[2] In the absence of information for adjusting egg losses on this basis, EPA chose to include eggs and larvae in the entrainment estimates to avoid underestimating age 0 losses.

With these caveats in mind, the following sections present the results of EPA's data compilations. The data are grouped by water body type and are presented in summary tables that indicate the range of losses for the 15 species with the highest I&E rates based on the limited subset of data available to EPA. I&E losses are expressed as mean annual numbers on a per facility basis. Because the data do not represent a random sample of I&E losses, it was not appropriate to summarize the data statistically. It is also important to stress that because the data are not a statistical sample, the data presented here may not represent the true magnitude of losses. Thus, the data should be viewed only as general indicators of the potential range of I&E.

11.3 CWIS Impingement and Entrainment Impacts in Rivers

Freshwater rivers and streams are free-flowing bodies of water that do not receive significant inflows of water from oceans or bays. Current is typically highest in the center of a river and rapidly drops toward the edges and at depth because of increased friction with river banks and the bottom (Hynes, 1970; Allan, 1995). Close to and at the bottom, the current can become minimal. The range of flow conditions in undammed rivers helps explain why fish with very different habitat requirements can co-exist within the same stretch of surface water (Matthews, 1998).

[2] For species for which sufficient life history information is available, the Equivalent Adult Model (EAM) can be used to predict the number of individuals that would have survived to adulthood each year if entrainment at egg or larval stages had not occurred (Horst, 1975; Goodyear, C.P., 1978). The resulting estimate is known as the number of "equivalent adults."

In general, the shoreline areas along river banks support a high diversity of aquatic life. These are areas where light penetrates to the bottom and supports the growth of rooted vegetation. Suspended solids tend to settle along shorelines where the current slows, creating shallow, weedy areas that attract aquatic life. Riparian vegetation, if present, also provides cover and shade. Such areas represent important feeding, resting, spawning, and nursery habitats for many aquatic species. In temperate regions, the number of impingeable and entrainable organisms in the littoral zone of rivers increases during the spring and early summer when most riverine fish species reproduce. This concentration of aquatic organisms along river shorelines in turn attracts wading birds and other kinds of wildlife.

The data compiled by EPA indicate that fish species such as common carp (*Cyprinus carpio*), yellow perch (*Perca flavescens*), white bass (*Morone chrysops*), freshwater drum (*Aplodinotus grunniens)*, gizzard shad (*Dorosoma cepedianum*), and alewife are the main fishes harmed by CWIS located in rivers. Table 11-2 shows, in order of the greatest to least impact, the annual entrainment of eggs, larvae, and juvenile fish in rivers. Table 11-3 shows, in order of greatest to least impact, the annual impingement in the rivers for all age classes. These species occur in nearshore areas and/or have pelagic early life stages, traits that greatly increase their susceptibility to I&E.

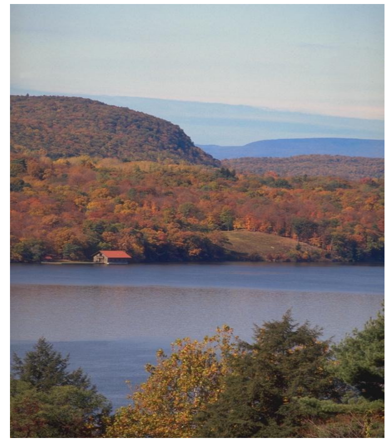


Table 11-2: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Rivers

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
common carp	*Cyprinus carpio*	7	20,500,000	859,000 - 79,400,000
yellow perch	*Perca flavescens*	4	13,100,000	434,000 - 50,400,000
white bass	*Morone chrysops*	4	12,800,000	69,400 - 49,600,000
freshwater drum	*Aplodinotus grunniens*	5	12,800,000	38,200 - 40,500,000
gizzard shad	*Dorosoma cepedianum*	4	7,680,000	45,800 - 24,700,000
shiner	*Notropis* spp.	4	3,540,000	191,000 - 13,000,000
channel catfish	*Ictalurus punctatus*	5	3,110,000	19,100 - 14,900,000
bluntnose minnow	*Pimephales notatus*	1	2,050,000	---
black bass	*Micropterus* spp.	1	1,900,000	---
rainbow smelt	*Osmerus mordax*	1	1,330,000	---
minnow	*Pimephales* spp.	1	1,040,000	---
sunfish	*Lepomis* spp.	5	976,000	4,230 - 4,660,000
emerald shiner	*Notropis atherinoides*	3	722,000	166,000 - 1,480,000
white sucker	*Catostomus commersoni*	5	704,000	20,700 - 2,860,000
mimic shiner	*Notropis volucellus*	2	406,000	30,100 - 781,000

Source: Hicks, 1977; Cole, 1978; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1997d; Cherry and Currie, 1998; Lewis and Seegert, 1998.

Table 11-3: Annual Impingement in the Rivers for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	3	1,030,000	199 - 3,050,000
gizzard shad	*Dorosoma cepedianum*	25	248,000	3,080 - 1,480,000
shiner	*Notropis* spp.	4	121,000	28 - 486,000
alewife	*Alosa pseudoharengus*	13	73,200	199 - 237,000
white perch	*Morone americana*	3	66,400	27,100 - 112,000
yellow perch	*Perca flavescens*	18	40,600	13 - 374,000
spottail shiner	*Notropis hudsonius*	10	28,500	10 - 117,000
freshwater drum	*Aplodinotus grunniens*	24	19,900	8 - 176,000
rainbow smelt	*Osmerus mordax*	11	19,700	7 - 119,000
skipjack herring	*Alosa chrysochons*	7	17,900	52 - 89,000
white bass	*Morone chrysops*	19	11,500	21 - 188,000
trout perch	*Percopsis omiscomaycus*	13	9,100	38 - 49,800
emerald shiner	*Notropis atherinoides*	17	7,600	109 - 36,100
blue catfish	*Ictalurus furcatus*	2	5,370	42 - 10,700
channel catfish	*Ictalurus punctatus*	23	3,130	3 - 25,600

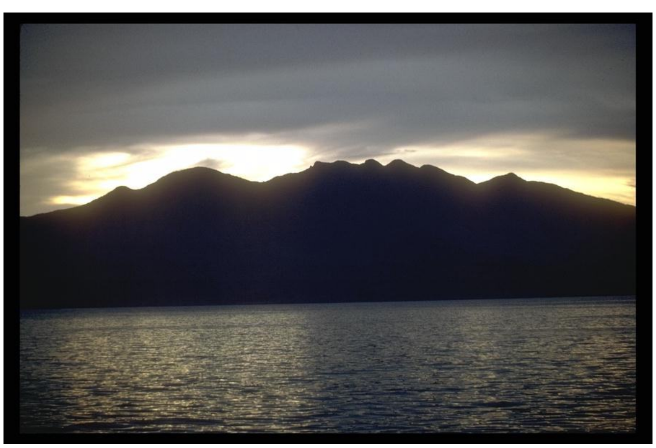
Source: Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Hicks, 1977; Sharma and Freeman, 1977; Stupka and Sharma, 1977; Energy Impacts Associates Inc., 1978; Geo-Marine Inc., 1978; Goodyear, C.D., 1978; Potter, 1978; Cincinnati Gas & Electric Company, 1979; Potter et al., 1979a, 1979b, 1979c, 1979d; Van Winkle et al., 1980; EA Science and Technology, 1987; Cherry and Currie, 1998; Michaud, 1998; Lohner, 1998.

11.4 CWIS Impingement and Entrainment Impacts in Lakes and Reservoirs

Lakes are inland bodies of open water located in natural depressions (Goldman and Horne, 1983). Lakes are fed by rivers, streams, springs, and/or local precipitation. Water currents in lakes are small or negligible compared to rivers, and are most noticeable near lake inlets and outlets.

Larger lakes are divided into three general zones — the littoral zone (shoreline areas where light penetrates to the bottom), the limnetic zone (the surface layer where most photosynthesis takes place), and the profundal zone (relatively deeper and colder offshore area) (Goldman and Horne, 1983). Each zone differs in its biological productivity and species diversity and hence in the potential magnitude of CWIS I&E impacts. The importance of these zones in relation to potential impacts of CWIS are discussed below.

The highly productive littoral zone extends farther and deeper in clear lakes than in turbid lakes. In small, shallow lakes, the littoral zone can be quite extensive and even include the entire water body. As along river banks, this zone supports high primary productivity and biological diversity. It is used by a host of fish species, benthic invertebrates, and zooplankton for feeding, resting, and reproduction, and as nursery habitat. Many fish species adapted to living in the colder profundal zone also move to shallower in-shore areas to spawn, e.g., lake trout (*Salmo namycush*) and various deep water sculpin species (*Cottus* spp.).



Many fish species spend most of their early development in and around the littoral zone of lakes. These shallow waters warm up rapidly in spring and summer, offer a variety of different habitats (submerged plants, boulders, logs, etc.) in which to hide or feed, and stay well-oxygenated throughout the year. Typically, the littoral zone is a major contributor to the total primary productivity of lakes (Goldman and Horne, 1983).

The limnetic zone accounts for the vast majority of light that is absorbed by the water column. In contrast to the high biological activity observed in the nearshore littoral zone, the offshore limnetic zone supports fewer species of fish and invertebrates. However, during certain times of year, some fish and invertebrate species spend the daylight hours hiding on the bottom and rise to the surface of the limnetic zone at night to feed and reproduce. Adult fish may migrate through the limnetic zone during seasonal spawning migrations. The juvenile stages of numerous aquatic insects — such as caddisflies, stoneflies, mayflies, dragonflies, and damselflies — develop in sediments at the bottom of lakes but move through the limnetic zone to reach the surface and fly away. This activity attracts foraging fish.

The deeper, colder profundal zone of a lake does not support rooted plants because insufficient light penetrates at these depths. For the same reason, primary productivity by phytoplankton is minimal. However, a well-oxygenated profundal zone can support a variety of benthic invertebrates or cold-water fish, e.g., brown trout (*Salmo trutta*), lake trout, and ciscoes (*Coregonus* spp.). With few exceptions (such as cisces or whitefish), these species seek out shallower areas to spawn, either in littoral areas or in adjacent rivers and streams, where they may become susceptible to CWIS.

Most of the larger rivers in the United States have one or more dams that create artificial lakes or reservoirs. Reservoirs have some characteristics that mimic those of natural lakes, but large reservoirs differ from most lakes in that they obtain most of their water from a large river instead of from groundwater recharge or from smaller creeks and streams.

The fish species composition in reservoirs may or may not reflect the native assemblages found in the pre-dammed river. Dams create two significant changes to the local aquatic ecosystem that can alter the original species composition: (1) blockages that prevent anadromous species from migrating upstream, and (2) altered riverine habitat that can eliminate species that cannot readily adapt to the modified hydrologic conditions.

Reservoirs typically support littoral zones, limnetic zones, and profundal zones, and the same concepts outlined above for lakes apply to these bodies of water. For example, compared to the profundal zone, the littoral zone along the edges of reservoirs supports greater biological diversity and provides prime habitat for spawning, feeding, resting, and protection for numerous fish and zooplankton species. However, there are also several differences. Reservoirs often lack extensive shallow areas along their edges because their banks have been engineered or raised to contain extra water and prevent flooding. In mountainous areas, the banks of reservoirs may be quite steep and drop off precipitously with little or no littoral zone. As with lakes and rivers, however, CWIS located in shallower water have a higher probability of entraining or impinging organisms.

Results of EPA's data compilation indicate that fish species most commonly affected by CWIS located on lakes and reservoirs are the same as the riverine species that are most susceptible, including alewife (*Alosa pseudoharengus*), drum (*Aplondinotus* spp.), and gizzard shad (*Dorsoma cepedianum*) (Tables 11-4 and 11-5).

Table 11-4: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Reservoirs and Lakes (excluding the Great Lakes)

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)
drum	*Aplondinotus* spp.	1	15,600,000
sunfish	*Lepomis* spp.	1	10,600,000
gizzard shad	*Dorosoma cepedianum*	1	9,550,000
crappie	*Pomoxis* spp.	1	8,500,000
alewife	*Alosa pseudoharengus*	1	1,730,000

Source: Michaud, 1998; Spicer et al., 1998.

Table 11-5: Annual Impingement in Reservoirs and Lakes (excluding the Great Lakes) for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
threadfin shad	*Dorosoma petenense*	4	678,000	203,000 - 1,370,000
alewife	*Alosa pseudoharengus*	4	201,000	33,100 - 514,000
skipjack herring	*Alosa chrysochons*	1	115,000	---
bluegill	*Lepomis macrochirus*	6	48,600	468 - 277,000
gizzard shad	*Dorosoma cepedianum*	5	41,100	829 - 80,700
warmouth sunfish	*Lepomis gulosus*	4	39,400	31 - 157,000
yellow perch	*Perca flavescens*	2	38,900	502 - 114,000
freshwater drum	*Aplodinotus grunniens*	4	37,500	8 - 150,000
silver chub	*Hybopsis storeriana*	1	18,200	---
black bullhead	*Ictalurus melas*	3	10,300	171 - 30,300
trout perch	*Percopsis omiscomaycus*	2	8,750	691 - 16,800
northern pike	*Esox lucius*	2	7,180	154 - 14,200
blue catfish	*Ictalurus furcatus*	1	3,350	---
paddlefish	*Polyodon spathula*	2	3,160	1,940 - 4,380
inland (tidewater) silverside	*Menidia beryllina*	1	3,100	---

Source: *Tennessee Division of Forestry, Fisheries, and Wildlife Development, 1976; Tennessee Valley Authority, 1976; Benda and Houtcooper, 1977; Freeman and Sharma, 1977; Sharma and Freeman, 1977; Tennessee Valley Authority, 1977; Spicer et al., 1998; Michaud, 1998.*

11.5 CWIS Impingement and Entrainment Impacts in the Great Lakes

The Great Lakes were carved out by glaciers during the last ice age (Bailey and Smith, 1981). They contain nearly 20% of the earth's fresh water, or about 23,000 km^3 (5,500 cu. mi.) of water, covering a total area of 244,000 km^2 (94,000 sq. mi.). There are five Great Lakes: Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario. Although part of a single system, each lake has distinct characteristics. Lake Superior is the largest by volume, with a retention time of 191 years, followed by Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario.

Water temperatures in the Great Lakes strongly influence the physiological processes of aquatic organisms, affecting growth, reproduction, survival, and species temporal and spatial distribution. During the spring, many fish species inhabit shallow, warmer waters where temperatures are closer to their thermal optimum. As water temperatures increase, these species migrate to deeper water. For species that are near the northern limit of their range, the availability of shallow, sheltered habitats that warm early in the spring is probably essential for survival (Lane et al., 1996a). For other species, using warmer littoral areas increases the growing season and may significantly increase production.

Some 80% of Great Lakes fish use the littoral zone for at least part of the year (Lane et al., 1996a). Of 139 Great Lakes fish species reviewed by Lane et al. (1996b), all but the deepwater ciscoes (*Coregonus* spp.) and deepwater sculpin (*Myxocephalus thompsoni*) use waters less than 10 m deep as nursery habitat.

A large number of thermal-electric plants located on the Great Lakes draw their cooling water from the littoral zone, resulting in high I&E of several fish species of commercial, recreational, and ecological importance, including alewife, gizzard shad, yellow perch, rainbow smelt, and lake trout (Tables 11-6 to 11-9).

Table 11-6: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in the Great Lakes				
Common Name	**Scientific Name**	**Number of Facilities**	**Mean Annual Entrainment per Facility (fish/year)**	**Range**
alewife	*Alosa pseudoharengus*	5	526,000,000	3,930,000 - 1,360,000,000
rainbow smelt	*Osmerus mordax*	5	90,500,000	424,000 - 438,000,000
lake trout	*Salmo namaycush*	1	116,000	---

Source: Texas Instruments Inc., 1978; Michaud, 1998.

Table 11-7: Annual Entrainment of Larval Fish in the Great Lakes by Lake		
Lake	**Number of Facilities**	**Total Annual Entrainment (fish/year)**
Erie	16	255,348,164
Michigan	25	196,307,405
Ontario	11	176,285,758
Huron	6	81,462,440
Superior	14	4,256,707

Source: Kelso and Milburn, 1979.

Table 11-8: Annual Impingement of Fish in the Great Lakes for All Age Classes Combined				
Common Name	**Scientific Name**	**Number of Facilities**	**Mean Annual Impingement per Facility (fish/year)**	**Range**
alewife	*Alosa pseudoharengus*	15	1,470,000	355 - 5,740,000
gizzard shad	*Dorosoma cepedianum*	6	185,000	25 - 946,000
rainbow smelt	*Osmerus mordax*	15	118,000	78 - 549,000
threespine stickleback	*Gasterosteus aculeatus*	3	60,600	23,200 - 86,200
yellow perch	*Perca flavescens*	9	29,900	58 - 127,000
spottail shiner	*Notropis hudsonius*	8	22,100	5 - 62,000
freshwater drum	*Aplodinotus grunniens*	4	18,700	2 - 74,800
emerald shiner	*Notropis atherinoides*	4	7,250	3 - 28,600
trout perch	*Percopsis omiscomaycus*	5	5,630	30 - 23,900
bloater	*Coregonus hoyi*	2	4,980	3,620 - 6,340
white bass	*Morone chrysops*	1	4,820	--
slimy sculpin	*Cottus cognatus*	4	3,330	795 - 5,800
goldfish	*Carassius auratus*	3	2,620	4 - 7,690
mottled sculpin	*Cottus bairdi*	3	1,970	625 - 3,450
common carp	*Cyprinus carpio*	4	1,110	16 - 4,180
pumpkinseed	*Lepomis gibbosus*	4	1,060	14 - 3,920

Source: Benda and Houtcooper, 1977; Sharma and Freeman, 1977; Texas Instruments Inc., 1978; Thurber and Jude, 1985; Lawler Matusky & Skelly Engineers, 1993a; Michaud, 1998.

Table 11-9: Annual Impingement of Fish in the Great Lakes by Lake

Lake	Number of Facilities	Total Annual Impingement (fish/year)
Erie	16	22,961,915
Michigan	25	15,377,339
Ontario	11	14,483,271
Huron	6	7,096,053
Superior	14	243,683

Source: Kelso and Milburn, 1979.

The I&E estimates of Kelso and Milburn (1979) presented in Tables 11-7 and 11-9 were derived using methods that differed in a number of ways from EPA's estimation methods, and therefore the data are not strictly comparable. First, the Kelso and Milburn (1979) data represent total annual losses per lake, whereas EPA's estimates are on a per facility basis. In addition, the estimates of Kelso and Milburn (1979) are based on extrapolation of losses to facilities for which data were unavailable using regression equations relating losses to plant size.

Despite the differences in estimation methods, when converted to an annual average per facility, the impingement estimates of Kelso and Milburn (1979) are within the range of EPA's estimates. For example, the average annual impingement of 675,980 fish per facility based on Kelso and Milburn's (1979) data is comparable to EPA's high estimate of 1,470,000 for alewife.

On the other hand, EPA's entrainment estimates include eggs and larvae and are therefore substantially larger than those of Kelso and Milburn (1979), which result from converting eggs and larvae to an equivalent number of fish. Because of the high natural mortality of fish eggs and larvae, entrainment losses expressed as the number that would have survived to become fish are much smaller than the original number of eggs and larvae entrained (Horst, 1975; Goodyear, 1978). Viewed together, the two types of estimates give an indication of the possible upper and lower bounds of annual entrainment per facility (e.g., an annual average of 8,018,657 fish based on Kelso and Milburn's data compared to EPA's highest estimate of 526,000,000 organisms based on the average for alewife).

11.6 CWIS Impingement and Entrainment Impacts in Estuaries

Estuaries are semi-enclosed bodies of water that have an unimpaired natural connection with the open ocean and within which sea water is diluted with fresh water derived from land. Estuaries are created and sustained by dynamic interactions among oceanic and freshwater environments, resulting in a rich array of habitats used by both terrestrial and aquatic species (Day et al., 1989). Because of the high biological productivity and sensitivity of estuaries, adverse environmental impacts are more likely to occur at CWIS located in estuaries than in other water body types.

Numerous commercially, recreationally, and ecologically important fish and shellfish species spend part or all of their life cycle within estuaries. Marine fish that spawn offshore take advantage of prevailing inshore currents to transport their eggs, larvae, or juveniles into estuaries where they hatch or mature. Inshore areas along the edges of estuaries support high rates of primary productivity and are used by numerous aquatic species for feeding and as nursery habitats. This high level of biological activity makes these shallow littoral zone habitats highly susceptible to I&E impacts from CWIS.

Estuarine species that show the highest rates of I&E in the studies reviewed by EPA include bay anchovy (*Anchoa mitchilli*), tautog (*Tautoga onitis*), Atlantic menhaden (*Brevoortia tyrannus*), gulf menhaden (*Brevoortia patronus*), winter flounder (*Pleuronectes americanus*), and weakfish (*Cynoscion regalis*) (Tables 11-10 and 11-11).

During spring, summer, and fall, various life stages of these and other estuarine fish show considerable migratory activity. Adults move in from the ocean to spawn in the marine, brackish, or freshwater portions of estuaries or their associated rivers; the eggs and larvae can be planktonic and move about with prevailing currents or by using selective tidal transport; juveniles actively move upstream or downstream in search of optimal nursery habitat; and young adult anadromous fish move out into the ocean to reach sexual maturity. Because of the many complex movements of estuarine-dependent species, a CWIS located almost anywhere in an estuary can harm both resident and migratory species as well as related freshwater, estuarine, and marine food webs.

Table 11-10: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Estuaries

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	18,300,000,000	12,300,000,000 - 24,400,000,000
tautog	*Tautoga onitis*	1	6,100,000,000	---
Atlantic menhaden	*Brevoortia tyrannus*	2	3,160,000,000	50,400,000 - 6,260,000,000
winter flounder	*Pleuronectes americanus*	1	952,000,000	---
weakfish	*Cynoscion regalis*	2	339,000,000	99,100,000 - 579,000,000
hogchoker	*Trinectes maculatus*	1	241,000,000	---
Atlantic croaker	*Micropogonias undulatus*	1	48,500,000	---
striped bass	*Morone saxatilis*	4	19,200,000	111,000 - 74,800,000
white perch	*Morone americana*	4	16,600,000	87,700 - 65,700,000
spot	*Leiostomus xanthurus*	1	11,400,000	---
blueback herring	*Alosa aestivalis*	1	10,200,000	---
alewife	*Alosa pseudoharengus*	1	2,580,000	---
Atlantic tomcod	*Microgadus tomcod*	3	2,380,000	2,070 - 7,030,000
American shad	*Alosa sapidissima*	1	1,810,000	---

Source: U.S. EPA, 1982; Lawler Matusky & Skelly Engineers, 1983; DeHart, 1994; PSE&G, 1999.

Table 11-11: Annual Impingement in Estuaries for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
gulf menhaden	*Brevoortia patronus*	2	76,000,000	2,990,000 - 149,000,000
smooth flounder	*Liopsetta putnami*	1	3,320,000	--
threespine stickleback	*Gasterosteus aculeatus*	4	866,000	123 - 3,460,000
Atlantic menhaden	*Brevoortia tyrannus*	12	628,000	114 - 4,610,000
rainbow smelt	*Osmerus mordax*	4	510,000	737 - 2,000,000
bay anchovy	*Anchoa mitchilli*	9	450,000	1,700 - 2,750,000
weakfish	*Cynoscion regalis*	4	320,000	357 - 1,210,000
Atlantic croaker	*Micropogonias undulatus*	8	311,000	13 - 1,500,000
spot	*Leiostomus xanthurus*	10	270,000	176 - 647,000
blueback herring	*Alosa aestivalis*	7	205,000	1,170 - 962,000
white perch	*Morone americana*	14	200,000	287 - 1,380,000
threadfin shad	*Dorosoma petenense*	1	185,000	---
lake trout	*Salmo namaycush*	1	162,000	---
gizzard shad	*Dorosoma cepedianum*	6	125,000	2,058 - 715,000
silvery minnow	*Hybognathus nuchalis*	1	73,400	---

Source: Consolidated Edison Company of New York Inc., 1975; Lawler Matusky & Skelly Engineers, 1975, 1976; Stupka and Sharma, 1977; Lawler et al., 1980; Texas Instruments Inc., 1980; Van Winkle et al., 1980; Consolidated Edison Company of New York Inc. and New York Power Authority, 1983; Normandeau Associates Inc., 1984; EA Science and Technology, 1987; Lawler Matusky & Skelly Engineers, 1991; Richkus and McLean, 1998; PSE&G, 1999; New York State Department of Environmental Conservation, No Date.

11.7 CWIS Impingement and Entrainment Impacts in Oceans

Oceans are marine open coastal waters with salinity greater than or equal to 30 parts per thousand (Ross, 1995). CWIS in oceans are usually located over the continental shelf, a shallow shelf that slopes gently out from the coastline an average of 74 km (46 miles) to where the sea floor reaches a maximum depth of 200 m (660 ft) (Ross, 1995). The deep ocean extends beyond this region. The area over the continental shelf is known as the Neritic Province and the area over the deep ocean is the Oceanic Province (Meadows and Campbell, 1978).

Vertically, the upper, sunlit epipelagic zone over the continental shelf averages about 100 m in depth (Meadows and Campbell, 1978). This zone has pronounced light and temperature gradients that vary seasonally and influence the temporal and spatial distribution of marine organisms.

In oceans, the littoral zone encompasses the photic zone of the area over the continental shelf. As in other water body types, the littoral zone is where most marine organisms concentrate. The littoral zone of oceans is of particular concern in the context of section 316(b) because this biologically productive zone is also where most coastal utilities withdraw cooling water.

The morphology of the continental shelf along the U.S. coastline is quite varied (NRC, 1993). Along the Pacific coast of the United States the continental shelf is relatively narrow, ranging from 5 to 20 km (3 to 12 miles), and is cut by several steep-sided submarine canyons. As a result, the littoral zone along this coast tends to be narrow, shallow, and steep. In contrast, along most of the Atlantic coast of the United States, there is a wide, thick, and wedge-shaped shelf that extends as much as 250 km (155 miles) from shore, with the greatest widths generally opposite large rivers. Along the Gulf coast, the shelf ranges from 20 to 50 km (12 to 31 miles).

The potential for I&E in coastal areas can be quite high, not only because CWIS are located in the productive areas over the continental shelf where many species reproduce, but also because nearshore areas within bays, estuaries, wetlands, or coastal rivers provide nursery habitat. In addition, the early life stages of many species are planktonic, and tides and currents can carry these organisms over large areas. The abundance of plankton in temperate regions is seasonal, with greater numbers in spring and summer and fewer numbers in winter.

An additional concern for CWIS in coastal areas pertains to the presence of marine mammals and reptiles, including threatened and endangered species of sea turtles. These species are known to enter submerged offshore CWIS and can drown once inside the intake tunnel.

In addition to many of the species discussed in the section on estuaries, other fish species found in near coastal waters that are of commercial, recreational, or ecological importance and are particularly vulnerable to I&E include silver perch (*Bairdiella chrysura*), cunner (*Tautogolabrus adspersus*), several anchovy species, scaled sardine (*Harengula jaguana)*, and queenfish (*Seriphus politus*) (Tables 11-12 and 11-13).

Table 11-12: Annual Entrainment of Eggs, Larvae, and Juvenile Fish in Oceans

Common Name	Scientific Name	Number of Facilities	Mean Annual Entrainment per Facility (fish/year)	Range
bay anchovy	*Anchoa mitchilli*	2	44,300,000,000	9,230,000,000 - 79,300,000,000
silver perch	*Bairdiella chrysura*	2	26,400,000,000	8,630,000 - 52,800,000,000
striped anchovy	*Anchoa hepsetus*	1	6,650,000,000	---
cunner	*Tautogolabrus adspersus*	2	1,620,000,000	33,900,000 - 3,200,000,000
scaled sardine	*Harengula jaguana*	1	1,210,000,000	---
tautog	*Tautoga onitis*	2	911,000,000	300,000 - 1,820,000,000
clown goby	*Microgobius gulosus*	1	803,000,000	---
code goby	*Gobiosoma robustum*	1	680,000,000	---
sheepshead	*Archosargus probatocephalus*	1	602,000,000	---
kingfish	*Menticirrhus* spp.	1	542,000,000	---
pigfish	*Orthopristis chrysoptera*	2	459,000,000	755,000 - 918,000,000
sand sea trout	*Cynoscion arenarius*	1	325,000,000	---
northern kingfish	*Menticirrhus saxatilis*	1	322,000,000	---
Atlantic mackerel	*Scomber scombrus*	1	312,000,000	---
Atlantic bumper	*Chloroscombrus chrysurus*	1	298,000,000	---

Source: Conservation Consultants Inc., 1977; Stone & Webster Engineering Corporation, 1980; Florida Power Corporation, 1985; Normandeau Associates Inc., 1994; Jacobsen et al., 1998; Northeast Utilities Environmental Laboratory, 1999.

Table 11-13: Annual Impingement in Oceans for All Age Classes Combined

Common Name	Scientific Name	Number of Facilities	Mean Annual Impingement per Facility (fish/year)	Range
queenfish	*Seriphus politus*	2	201,000	19,800 - 382,000
polka-dot batfish	*Ogcocephalus radiatus*	1	74,500	---
bay anchovy	*Anchoa mitchilli*	2	49,500	11,000 - 87,900
northern anchovy	*Engraulis mordax*	2	36,900	26,600 - 47,200
deepbody anchovy	*Anchoa compressa*	2	35,300	34,200 - 36,400
spot	*Leiostomus xanthurus*	1	28,100	---
American sand lance	*Ammodytes americanus*	2	20,700	886 - 40,600
silver perch	*Bairdiella chrysura*	2	20,500	12,000 - 29,000
California grunion	*Caranx hippos*	1	18,300	---
topsmelt	*Atherinops affinis*	2	18,200	4,320 - 32,300
alewife	*Alosa pseudoharengus*	2	16,900	1,520 - 32,200
pinfish	*Lagodon rhomboides*	1	15,200	---
slough anchovy	*Anchoa delicatissima*	3	10,900	2,220 - 27,000
walleye surfperch	*Hyperprosopon argenteum*	1	10,200	---
Atlantic menhaden	*Brevoortia tyrannus*	3	7,500	861 - 20,400

Source: Stone & Webster Engineering Corporation, 1977; Stupka and Sharma, 1977; Tetra Tech Inc., 1978; Stone and Webster Engineering Corporation, 1980; Florida Power Corporation, 1985; Southern California Edison Company, 1987; SAIC, 1993; EA Engineering, Science and Technology, 1997; Jacobsen et al., 1998.

11.8 Summary of Impingement and Entrainment Data

The data evaluated by EPA indicate that fish species with free-floating, early life stages are those most susceptible to CWIS impingement and entrainment impacts. Such planktonic organisms lack the swimming ability to avoid being drawn into intake flows. Species that spawn in nearshore areas, have planktonic eggs and larvae, and are small as adults experience even greater impacts because both new recruits and the spawning adults are affected (e.g., bay anchovy in estuaries and oceans).

EPA's data review also indicates that fish species in estuaries and oceans experience the highest rates of I&E. These species tend to have planktonic eggs and larvae, and tidal currents carry planktonic organisms past intakes multiple times, increasing the probability of I&E. In addition, fish spawning and nursery areas are located throughout estuaries and near coastal waters, making it difficult to avoid locating intakes in areas where fish are present.

11.9 Potential Benefits of Section 316(b) Regulation

11.9.1 Benefits Concepts, Categories, and Causal Links

This section provides a qualitative description of the types of benefits that are expected from the section 316(b) New Facility Rule. Although valuing the changes in environmental quality that arise from the rule is a principal desired outcome for the Agency's policy assessment framework, time and data constraints do not permit a quantified assessment of the economic benefits of the final rule.

As noted in previous sections of this chapter, changes in CWIS design, location, or capacity can reduce I&E rates. These changes in I&E can potentially yield significant ecosystem improvements in terms of the number of fish that avoid premature mortality. This in turn is expected to increase local and regional fishery populations, and ultimately contribute to the enhanced environmental functioning of affected water bodies (rivers, lakes, estuaries, and oceans). Finally, the economic welfare of human populations is expected to increase as a consequence of the improvements in fisheries and associated aquatic ecosystem functioning. Potential ecological outcomes and related economic benefits from anticipated reductions in adverse effects of CWIS are identified below along with an explanation of the basic economic concepts applicable to the economic benefits, including benefit categories and taxonomies, service flows, and market and nonmarket goods and services.

11.9.2 Applicable Economic Benefit Categories

Key challenges in benefits assessment include uncertainties and data gaps, as well as the fact that many of the goods and services beneficially affected by the change in new facility I&E are not traded in the marketplace. Thus there are numerous instances — including this final section 316(b) rule for new facilities — when it is not feasible to confidently assign monetary values to some beneficial outcomes. In such instances, benefits are described and considered qualitatively. This is the case for the rule for new facility CWIS. At this time, there is only general information about the location of most new facilities, and in most cases details of facility and environmental characteristics are unknown. As a result, it is not possible to do a detailed analysis of potential monetary benefits associated with the final regulations.

11.9.3 Benefit Category Taxonomies

The term "economic benefits" here refers to the dollar value associated with all the expected positive impacts of the section 316(b) New Facility Rule. Conceptually, the monetary value of benefits is the sum of the predicted changes in "consumer and producer surplus." These surplus measures are standard and widely accepted terms of applied welfare economics, and reflect the degree of well-being derived by economic agents (e.g., people or firms) given different levels of goods and services, including those associated with environmental quality.[3]

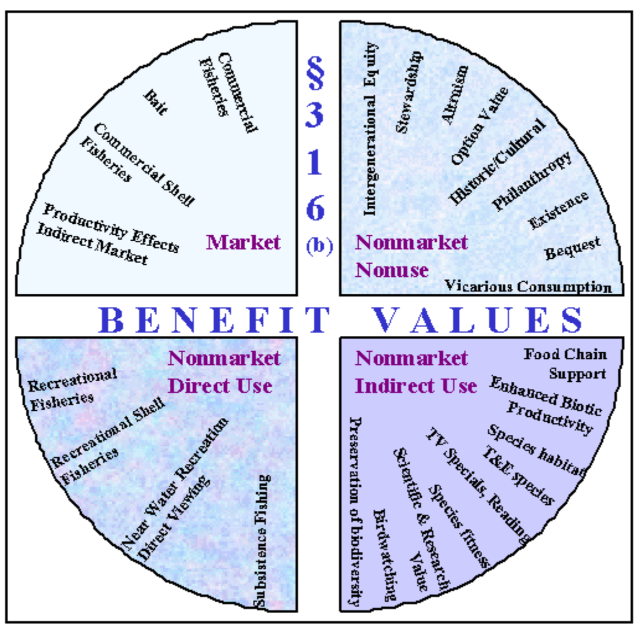
[3] Technically, consumer surplus reflects the difference between the "value" an individual places on a good or service (as reflected by the individual's "willingness to pay" for that unit of the good or service) and the "cost" incurred by that individual to acquire it (as reflected by the "price" of a commodity or service, if it is provided in the marketplace). Graphically, this is the area bounded from above by the demand curve and below by the market clearing price. Producer surplus is a similar concept, reflecting the difference between the market price a producer can obtain for a good or service and the actual cost of producing that unit of the commodity.

The economic benefits of activities that improve environmental conditions can be categorized in many different ways. The various terms and categories offered by different authors can lead to some confusion with semantics. However, the most critical issue is to try not to omit any relevant benefit, and at the same time avoid potential double counting of benefits.

One common typology for benefits of environmental programs is to divide them into three main categories: (1) economic welfare (e.g., changes in the well-being of humans who derive use value from market or nonmarket goods and services such as fisheries); (2) human health (e.g., the value of reducing the risk of premature fatality due to changing exposure to environmental exposure); and (3) nonuse values (e.g., stewardship values for the desire to preserve threatened and endangered species). For the section 316(b) New Facility Rule, however, this typology does not convey all the intricacies of how the rule might generate benefits. Further, human health benefits are not anticipated. Therefore, another categorization may be more informative.

Figure 11-1 outlines the most prominent categories of benefit values for the section 316(b) New Facility Rule. The four quadrants are divided by two principles: (1) whether the benefit can be tracked in a market (i.e., market goods and services) and (2) how the benefit of a nonmarket good is received by human beneficiaries (either from direct use of the resource, from indirect use, or from nonuse).

Figure 11-1: Section 316(b) Benefit Values



Market benefits are best typified by commercial fisheries, where a change in fishery conditions will manifest itself in the price, quantity, and/or quality of fish harvests. The fishery changes thus result in changes in the marketplace, and can be evaluated based on market exchanges.

Direct use benefits include the value of improved environmental goods and services used and valued by people (whether or not they are traded in markets). A typical nonmarket direct use would be recreational angling, in which participants enjoy a welfare gain when the fishery improvement results in a more enjoyable angling experience (e.g., higher catch rates).

Indirect use benefits refer to changes that contribute, through an indirect pathway, to an increase in welfare for users (or nonusers) of the resource. An example of an indirect benefit would be when the increase in the number of forage fish enables the population of valued predator species to improve (e.g., when the size and numbers of prized recreational or commercial fish increase because their food source has been improved). In such a context, the I&E impacts on a forage species will indirectly result in welfare gains for recreational or commercial anglers.

Nonuse benefits — also known as passive use values — reflect the values individuals assign to improved ecological conditions apart from any current, anticipated, or optional use by them. Some economists consider option values to be a part of nonuse values because the option value is not derived from actual current use, whereas other writers place it in a use category (because the option value is associated with preserving opportunity for a future use of the resource). For convenience, we place option value in the nonuse category.

11.9.4 Direct Use Benefits

Direct use benefits are the simplest to envision. The welfare of commercial, recreational, and subsistence fishermen is improved when fish stocks increase and their catch rates rise. This increase in stocks may be induced by reduced I&E of species sought by fishermen, or through reduced I&E of forage and bait fish, which leads to increases in populations of commercial and recreational species. For subsistence fishermen, the increase in fish stocks may reduce the amount of time spent fishing for their meals or increase the number of meals they are able to catch. For recreational anglers, more fish and higher catch rates may increase the enjoyment of a fishing trip and may also increase the number of fishing trips taken. For commercial fishermen, larger fish stocks may lead to increased revenues through increases in total landings and/or increases in the catch per unit of effort (i.e., lower costs per fish caught). Increases in catch may also lead to growth in related commercial enterprises, such as commercial fish cleaning/filleting, commercial fish markets, recreational charter fishing, and fishing equipment sales.

Evidence that these use benefits are valued by society can be seen in the market. For example, in 1996 about 35 million recreational anglers spent nearly $38 billion on equipment and fishing trip related expenditures (US DOI, 1997) and the 1996 GDP from fishing, forestry, and agricultural services (not including farms) was about $39 billion (BEA, 1998). Clearly, these data indicate that the fishery resource is very important. Although these baseline values do not give us a sense of how benefits change with changes in environmental quality such as reduced I&E and increased fish stocks, even a change of 0.1% would translate into potential benefits of $40 million per year.

Commercial fishermen. The benefits derived from increased landings by commercial fishermen can be valued by looking at the market in which the fish are sold. The ideal measure of commercial fishing benefits is the producer surplus generated by the marginal increase in landings, but often the data required to compute the producer surplus are unavailable. In this case, revenues may be used as a proxy for producer surplus, with some assumptions and an adjustment. The assumptions are that (1) there will be no change in harvesting behavior or effort, but existing commercial anglers will experience an increase in landings, and (2) there will be no change in price. Given these assumptions, benefits can be estimated by calculating the expected increase in the value of commercial landings, and then translating the landed values into estimated increases in producer surplus. The economic literature (Huppert, 1990) suggests that producer surplus values for commercial fishing have been estimated to be approximately 90% of total revenue (landings values are a close proxy for producer surplus because the commercial fishing sector has very high fixed costs relative to its variable costs). Therefore, the marginal benefit from an increase in commercial landings can be estimated to be approximately 90% of the anticipated change in revenue.

Recreational users. The benefits of recreational use cannot be tracked in the market. However, there is extensive literature on valuing fishing trips and valuing increased catch rates on fishing trips. While it is likely that nearwater recreational users will gain benefits, it is unlikely that swimmers would perceive an important effect on their use of the ecosystem. Boaters may receive recreational value to the degree that enjoyment of their surroundings is an important part of their recreational pleasure or that fishing is a secondary reason for boating. Passive use values to these and other individuals are discussed below.

Primary studies of sites throughout the United States have shown that anglers value their fishing trips and that catch rates are one of the most important attributes contributing the quality of their trips.

Higher catch rates may translate into two components of recreational angling benefits: an increase in the value of existing recreational fishing trips, and an increase in recreational angling participation. The most promising approaches for quantifying and monetizing these two benefits components are benefits transfer (as a secondary method) and random utility modeling or RUM (as a primary research method).

To estimate the value of an improved recreational fishing experience, it is necessary to estimate the existing number of angling trips or days that are expected to be improved by reducing I&E. As with the commercial fishing benefits, it is important to identify the appropriate geographic scope when estimating these numbers. Once the existing angling numbers have been estimated, the economic value of an improvement (consumer surplus) can be estimated. The specific approach for estimating the value will depend on the economic literature that is most relevant to the specific characteristics of the study site. For example, some economic studies in the literature can be used to infer a factor (percentage increase) that can be applied to the baseline value of the fishery for specific changes in fishery conditions. Other primary studies simply provide an estimate of the incremental value attributable to an improvement in catch rate.

In some cases it may be reasonable to assume that increases in fish abundance (attributable to reducing I&E) will lead to an increase in recreational fishing participation. This would be particularly relevant in a location that has experienced such a severe impact to the fishery that the site is no longer an attractive location for recreational activity. Estimates of potential recreational activity post-regulation can be made based on similar sites with healthy fishery populations, on conservative estimates of the potential increase in participation (e.g., a 5% increase), or on recreational planning standards (densities or level of use per acre or stream mile). A participation model (as in a RUM application) could also be used to predict changes in the net addition to user levels from the improvement at an impacted site. The economic benefit of the increase in angling days then can be estimated using values from the economic literature for a similar type of fishery and angling experience.

Subsistence anglers. Subsistence use of fishery resources can be an important issue in areas where socioeconomic conditions (e.g., the number of low income households) or the mix of ethnic backgrounds make such angling economically or culturally important to a component of the community. In cases of Native American use of impacted fisheries, the value of an improvement can sometimes be inferred from settlements in similar legal cases (including natural resource damage assessments, or compensation agreements between impacted tribes and various government or other institutions in cases of resource acquisitions or resource use restrictions). For more general populations, the value of improved subsistence fisheries may be estimated from the costs saved in acquiring alternative food sources (assuming the meals are replaced rather than foregone).

11.9.5 Indirect Use Benefits

Indirect use benefits refer to welfare improvements that arise for those individuals whose activities are enhanced as an indirect consequence of the fishery or habitat improvements generated by the final new facility standards for CWIS. For example, the rule's positive impacts on local fisheries may, through the intricate linkages in ecologic systems, generate an improvement in the population levels and/or diversity of bird species in an area. This might occur, for example, if the impacted fishery is a desired source of food for an avian species of interest. Avid bird watchers might thus obtain greater enjoyment from their outings, as they are more likely to see a wider mix or greater numbers of birds. The increased welfare of the bird watchers is thus a legitimate but indirect consequence of the final rule's initial impact on fish.

There are many forms of potential indirect benefits. For example, a rule-induced improvement in the population of a forage fish species may not be of any direct consequence to recreational or commercial anglers. However, the increased presence of forage fish may well have an indirect affect on commercial and recreational fishing values because it enhances an important part of the food chain. Thus, direct improvements in forage species populations may well result in a greater number (and/or greater individual size) of those fish that are targeted by recreational or commercial anglers. In such an instance, the relevant recreational and commercial fishery benefits would be an indirect consequence of the final rule's initial impacts on lower levels of the aquatic ecosystem.

The data and methods available for estimating indirect use benefits depend on the specific activity that is enhanced. For example, an indirect improvement to recreational anglers would be measured in essentially the same manner discussed under the preceding discussion on direct use benefits (e.g., using a RUM model). However, the analysis requires one additional critical step — that of indicating the link between the direct impact of the final rule (e.g., improvements in forage species populations) and the indirect use that is ultimately enhanced (e.g., the recreationally targeted fish). Therefore, what is typically required for estimating indirect use benefits is ecologic modeling that captures the key linkages between the initial impact of the rule and its ultimate (albeit indirect) effect on use values. In the example of forage species, the change in forage fish populations would need to be analyzed in a manner that ultimately yields information on responses in recreationally targeted species (e.g., that can be linked to a RUM analysis).

11.9.6 Nonuse Benefits

Nonuse (passive use) benefits arise when individuals value improved environmental quality apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence (stewardship) and bequest (intergenerational equity) motives. Passive use values also may include the concept that some ecological services are valuable apart from any human uses or motives. Examples of these ecological services may include improved reproductive success for aquatic and terrestrial wildlife, increased diversity of aquatic and terrestrial wildlife, and improved conditions for recovery of threatened and endangered species.

Passive values can only be estimated in primary research through the use of direct valuation techniques such as contingent valuation method (CVM) surveys and related techniques (e.g., conjoint analysis using surveys). In the case of the final section 316(b) New Facility Rule, no primary research was feasible within the constraints faced by the Agency. If estimates were to be developed, EPA would need to rely on benefits transfer, with appropriate care and caveats clearly recognized.

One typical approach for estimating passive values is to apply a ratio between certain use-related benefits estimates and the passive use values anticipated for the same site and resource change. Freeman (1979) applied a rule of thumb in which he inferred that national-level passive benefits of water quality improvements were 50% of the estimated recreational fishing benefits. This was based on his review of the literature in those instances where nonuse and use values had been estimated for the same resource and policy change. Fisher and Raucher (1984) undertook a more in-depth and expansive review of the literature, found a comparable relationship between recreational angling benefits and nonuse values, and concluded that since nonuse values were likely to be positive, applying the 50% "rule of thumb" was preferred over omitting nonuse values from a benefits analysis entirely.

The 50% rule has since been applied frequently in EPA water quality benefits analyses (e.g., effluent guidelines RIAs for the iron and steel and pulp and paper sectors, and the RIA for the Great Lakes Water Quality Guidance). At times the rule has been extended to ratios higher than 50% (based on specific studies in the literature). However, the overall reliability and credibility of this type of approach is, as for any benefits transfer approach, dependent on the credibility of the underlying study and the comparability in resources and changes in conditions between the research survey and the section 316(b) New Facility Rule's impacts at selected sites. The credibility of the nonuse value estimate also is contingent on the reliability of the recreational angling estimates to which the 50% rule is applied.

A second potential approach to deriving estimates for section 316(b) passive use values is to use benefits transfer to apply an annual willingness-to-pay estimate per nonuser household (e.g., Mitchell and Carson, 1986; Carson and Mitchell, 1993) to all the households with passive use motives for the impacted water body. The challenges in this approach include defining the appropriate "market" for the impacted site (e.g., what are the boundaries for defining how many households apply), as well as matching the primary research scenario (e.g., "boatable to fishable") to the predicted improvements at the section 316(b)-impacted site.

For specific species, some nonuse valuation may be deduced using restoration-based costs as a proxy for the value of the change in stocks (or for threatened and endangered species the value of preserving the species). Where a measure of the approximate cost per individual can be deduced, and the number of individuals spared via BTA can be estimated, this may be a viable approach.

11.9.7 Summary of Benefits Categories

Table 11-14 displays the types of benefits categories expected to be affected by the section 316(b) New Facility Rule and the various data needs, data sources, and estimation approaches associated with each category. As described in sections 11.9.4 to 11.9.6, economic benefits can be broadly defined according to three categories: (1) direct use, (2) indirect use, and (3) nonuse (passive use) benefits. These benefits can be further categorized according to whether or not they are traded in the market. As indicated in Table 11-14, "direct use" benefits include both "marketed" and "nonmarketed" goods, whereas "nonuse" and "indirect use" benefits include only "nonmarketed" goods.

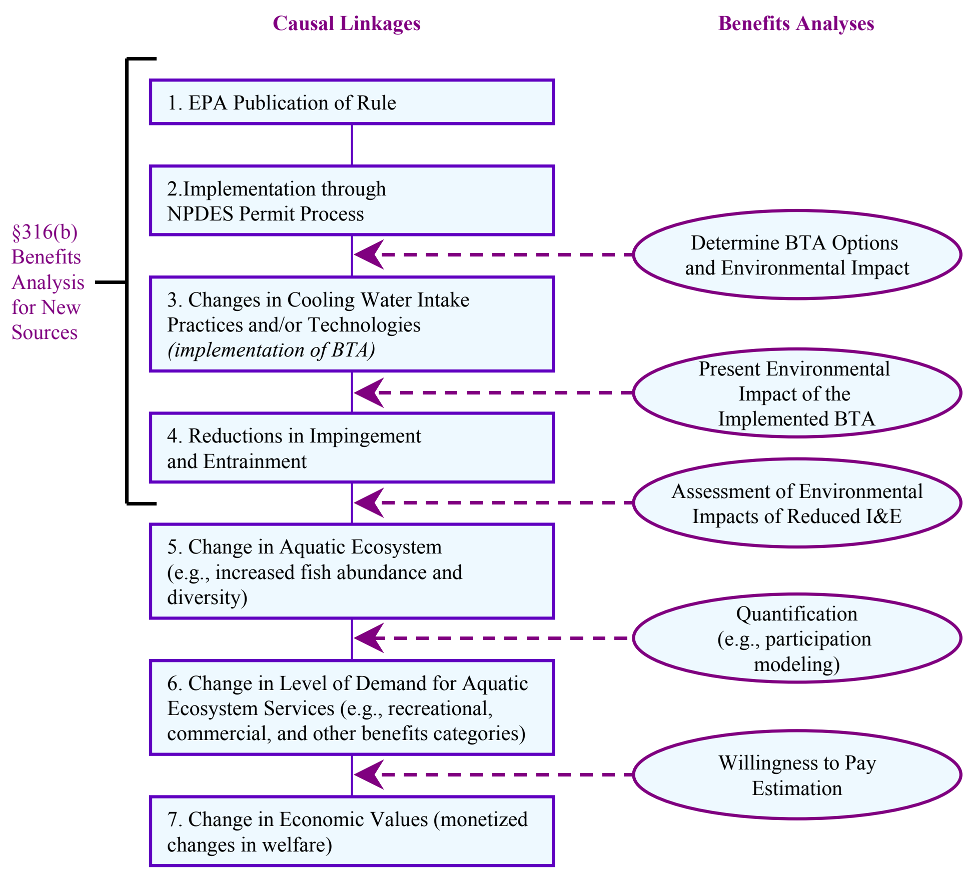
Table 11-14: Summary of Benefit Categories, Data Needs, Potential Data Sources, and Approaches

Benefits Category	Basic Data Needs	Potential Data Sources/Approaches
	Direct Use, Marketed Goods	
Increased commercial landings (fishing, shellfishing, and aquaculture)	▸ Estimated change in landings ▸ Estimated producer surplus	▸ Based on ecological modeling ▸ Based on available literature or 50% rule
	Direct Use, Nonmarketed Goods	
Improved value of a recreational fishing experience	▸ Estimated number of affected anglers ▸ Value of an improvement in catch rate, and possibly, value of an angling day	▸ Site-specific studies, national or statewide surveys ▸ Based on available literature
Increase in recreational fishing participation	▸ Estimated number of affected anglers or estimate of potential anglers ▸ Value of an angling day	▸ Site-specific studies, national or statewide surveys ▸ Based on available literature
Increase in subsistence fishing	▸ Estimated number of affected anglers or estimate of potential anglers ▸ Value of an angling day	▸ Site-specific studies, national or statewide surveys ▸ Based on available literature
	Nonuse and Indirect Use, Nonmarketed	
Increase in indirect values	▸ Estimated changes in ecological services (e.g., reproductive success of aquatic species) ▸ Restoration based on costs	▸ Based on ecological modeling ▸ Site-specific studies, national or statewide surveys
Increase in passive use values	▸ Apply stated preference approach, or benefits transfer	▸ Site-specific studies, national or statewide stated preference surveys

11.9.8 Causality: Linking the Section 316(b) Rule to Beneficial Outcomes

Understanding the anticipated economic benefits arising from changes in I&E requires understanding a series of physical and socioeconomic relationships linking the installation of Best Technology Available (BTA) to changes in human behavior and values. As shown in Figure 11-2, these relationships span a broad spectrum, including institutional relationships to define BTA (from policy making to field implementation), the technical performance of BTA, the population dynamics of the aquatic ecosystems affected, and the human responses and values associated with these changes.

Figure 11-2: Causal Linkages in the Benefits Analysis



The first two steps in Figure 11-2 reflect the institutional aspects of implementing the section 316(b) New Facility Rule. In step 3, the anticipated applications of BTA (or a range of BTA options) must be determined for the regulated entities. This technology forms the basis for estimating the cost of compliance, and provides the basis for the initial physical impact of the rule (step 4). Hence, the analysis must predict how implementation of BTAs (as predicted in step 3) translates into changes in I&E at the regulated CWIS (step 4). These changes in I&E then serve as input for the ecosystem modeling (step 5).

In moving from step 4 to step 5, the selected ecosystem model (or models) are used to assess the change in the aquatic ecosystem from the preregulatory baseline (e.g., losses of aquatic organisms before BTA) to the postregulatory conditions (e.g., losses after BTA implementation). The potential output from these steps includes estimates of reductions in I&E rates, and changes in the abundance and diversity of aquatic organisms of commercial, recreational, ecological, or cultural value, including threatened and endangered species.

In step 6, the analysis involves estimating how the changes in the aquatic ecosystem (estimated in step 5) translate into changes in level of demand for goods and services. For example, the analysis needs to establish links between improved fishery abundance, potential increases in catch rates, and enhanced participation. Then, in step 7, as an example, the value of the increased enjoyment realized by recreational anglers is estimated. These last two steps typically are the focal points of the economic benefits portion of the analysis. However, because of data and time constraints, this benefits analysis is limited to only the first four steps of the process.

11.10 Empirical Indications of Potential Benefits

The following discussion provides examples from existing facilities that offer some indication of the relative magnitude of monetary benefits that may be expected to result from the final new facility regulations.

The potential benefits of lower intake flows and 100% recirculation of flow are illustrated by comparisons of once-through and closed-cycle cooling (e.g., Brayton Point and Hudson River facilities). The potential benefits of additional requirements defined by regional permit directors are demonstrated by operational changes implemented to reduce impingement and entrainment (e.g., Pittsburg and Contra Costa facilities). The potential benefits of reducing losses of forage species are demonstrated by analysis of the biological and economic relationships among forage species and commercial and recreational fishery species (e.g., Ludington facility on Lake Michigan). Finally, the potential benefits of implementing additional technologies to increase survival of organisms impinged or entrained are illustrated by the application of modified intake screens and fish return systems (e.g., Salem Nuclear Generating Facility). These cases are discussed below.

An example of the potential benefits of minimizing intake flow is provided by data for the Brayton Point facility, located on Mt. Hope Bay in Massachusetts (NEPMRI, 1981, 1995; U.S. EPA, 1982). In the mid-1980s, the operation of Unit 4 at Brayton Point was changed from closed-cycle to once-through cooling, increasing flow by 48% from an average of 703 MGD before conversion to an average of 1045 MGD for the first 6 years post-conversion (Lawler, Matusky, and Skelly Engineers, 1993b). Although conversion to once-through cooling increased coolant flow and the associated heat load to Mt. Hope Bay, the facility requested the change because of electrical problems associated with Unit 4's saltwater spray cooling system (U.S. EPA, 1982). An analysis of fisheries data by the Rhode Island Division of Fish and Wildlife using a time series-intervention model indicated that there was an 87% reduction in finfish abundance in Mt. Hope Bay coincident with the Unit 4 modification (Gibson, 1996). The analysis also indicated that, in contrast, species abundance trends have been relatively stable in adjacent coastal areas and portions of Narragansett Bay that are not influenced by the operation of Brayton Pt.

Another example of the potential benefits of low intake flow is provided by an analysis of I&E losses at five Hudson River power plants. Estimated fishery losses under once-through compared to closed-cycle cooling indicated that an average reduction in intake flow of about 95% at the three facilities responsible for the greatest impacts would result in a 30-80% reduction in fish losses, depending on the species involved (Boreman and Goodyear, 1988). An economic analysis estimated monetary damages under once-through cooling based on the assumption that annual percent reductions in year classes of fish result in proportional reductions in fish stocks and harvest rates (Rowe et al., 1995). A low estimate of per facility damages was based on losses at all five facilities and a high estimate was based on losses at the three facilities that account for most of the impacts. Damage estimates under once-through cooling ranged from about $1.3 million to $6.1 million annually in 1999 dollars.

A third example demonstrates how I&E losses of forage species can lead to reductions in economically valued species. Jones and Sung (1993) applied a RUM to estimate fishery impacts of I&E by the Ludington Pumped-Storage plant on Lake Michigan. This method estimates changes in demand as a function of changes in catch rates. The Ludington facility is responsible for the loss of about 1-3% of the total Lake Michigan production of alewives, a forage species that supports valuable trout and salmon fisheries. Jones and Sung (1993) estimated that losses of alewife result in a loss of nearly 6% of the angler catch of trout and salmon each year. Based on RUM analysis, they estimated that if Ludington operations ceased, catch rates of trout and salmon species would increase by 3.3 to 13.7% annually, amounting to an estimated recreational angling benefit of $0.95 million per year (in 1999 dollars) for these species alone.

A fourth example indicates the potential benefits of operational BTA that might be required by regional permit Directors. Two plants in the San Francisco Bay/Delta, Pittsburg and Contra Costa, have made changes to their intake operations to reduce impingement and entrainment of striped bass (*Morone saxatilis*). These operational changes have also reduced incidental take of several threatened and endangered fish species, including the delta smelt *(Hypomesus transpacificus*) and several runs of chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). According to technical reports by the facilities, operational BTA reduced striped bass losses by 78% to 94%, representing an increase in striped bass recreational landings averaging about 100,000 fish each year (PG&E, 1996, 1997, 1998, 1999; Southern Energy California, 2000). A local study estimated that the consumer surplus of an additional striped bass caught by a recreational angler is $8.87 to $13.77 (Huppert, 1989). This implies a benefit to the recreational fishery, from reduced impingement and entrainment of striped bass alone, in the range of $887,000 to $1,377,000 annually. The monetary benefit of reduced impingement and entrainment of threatened and endangered species might be substantially greater.

The final example indicates the benefits of technologies that can be applied to maximize survival. In their 1999 permit renewal application, the Salem Nuclear Generating Station in the Delaware Estuary evaluated the potential benefits of dual-flow, fine-mesh traveling screens designed to achieve an approach velocity of 0.5 fps (PSEG, 1999). The facility estimated that use of this technology would have a total economic benefit of $3.64 million in 2000 dollars (Appendix F, Section IX, Table 12).

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